

Inelastic scattering of protons by O^{16}

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With 2 figures in the text

In this note we wish to give a brief report on some preliminary calculations concerning the inelastic scattering of 180 MeV protons by O^{16} . Our approach is quite similar to that used by Squires [1] for C^{12} . We describe the transition from the ground state to an excited state as the result of a single nucleon-nucleon collision described by the t -matrix for free nucleon-nucleon collisions. The incoming and outgoing proton waves, $\chi^{(\pm)}$ respectively, are approximated in the same way as done by Squires. The recent calculations of Bjorklund and Fernbach [2] indicate that the real central part of the optical potential is very small at 180 MeV. We believe also that the neglect of the spin-orbit part and the distortion of the waves on account of the Coulomb interaction do not introduce serious errors. The calculations by Bjorklund and Fernbach give a value about 22 MeV for the strength parameter of the imaginary central potential using a Woods-Saxon potential [3]. This would correspond to not more than 30 MeV for a Gaussian form and we have used this value in our calculations. This value is considerably smaller than the value 60 MeV used by Squires, but one should not attach too much significance to this difference because of the uncertainty in using an optical potential for these light nuclei.

The matrix t_{1k} , where 1 denotes the incident proton and k one of the particles in the target nucleus, is taken as

$$t_{1k} = \delta(\mathbf{r}_1 - \mathbf{r}_k) t'_{1k}(\theta), \quad (1)$$

where $t'_{1k}(\theta)$ is a matrix in the spin space of nucleons 1 and k . θ is the angle between the directions of the in- and outgoing wave vectors $\mathbf{k}_i$ and $\mathbf{k}_f$. In the expression for $t'_{1k}(\theta)$, written in the form given by Wolfenstein and Ashkin [4], only the following terms give non-vanishing contributions for O^{16} in our calculations:

$$t'_{1k} = a + c \sigma_1 \cdot \mathbf{n}, \quad (2)$$

where $\mathbf{n}$ is a unit vector perpendicular to $\mathbf{k}_i$ and $\mathbf{k}_f$. Here a and c are the average values for p - p and p - n scattering. The notation in (2) is the same as that used by Squires and in our calculations we have made use of the values calculated by him for nucleon-nucleon scattering at 180 MeV from the phase shifts by Gammel and Thaler [5].

We have studied the 6.14 MeV level, which we have treated in the L - S coupling

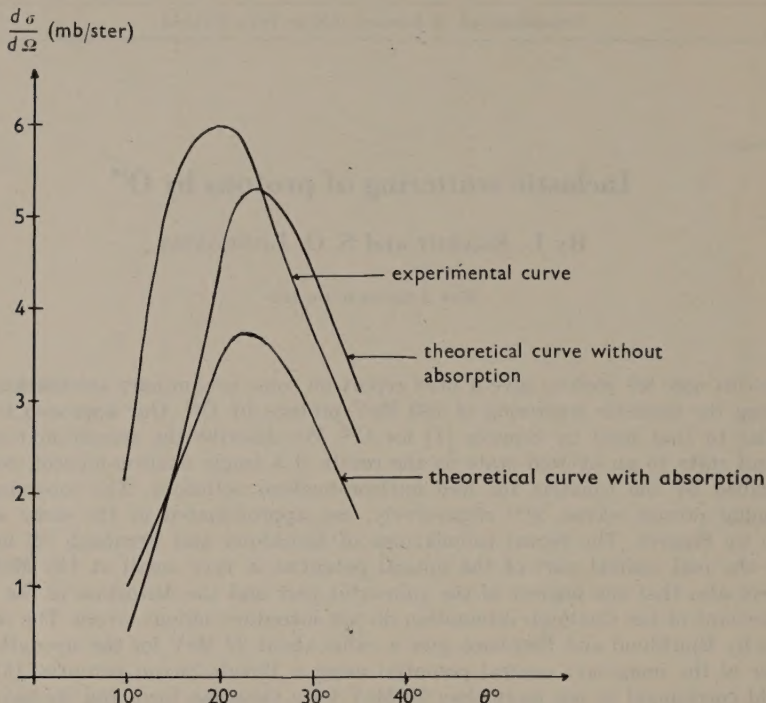


Fig. 1. The experimental and theoretical differential cross-sections for inelastic scattering of 180 MeV protons by O^{16} .

scheme as an excitation from the ground state S^4P^{12} with $L=S=T=0$ to the state $L=3$, $S=T=0$ in the $S^4P^{11}D^1$ configuration.

The following expression is obtained for the differential cross-section:

$$\frac{d\sigma}{d\Omega} = 16 [|a|^2 + |c|^2] \{ |J_0|^2 + 2 |J_2|^2 \}, \quad (3)$$

where

$$J_0 = 2\sqrt{\frac{1}{5}} I_{11} - \sqrt{\frac{2}{5}} I_{00}, \quad (3')$$

$$J_2 = 2\sqrt{\frac{2}{3}} I_{-11} - \sqrt{\frac{1}{3}} I_{20}$$

and

$$I_{m'm} = \langle 2m' | \chi_{\mathbf{k}_f}^{(-)*} \chi_{\mathbf{k}_i}^{(+)} | 1m \rangle. \quad (3'')$$

The matrix element in (3'') is taken between harmonic oscillator wave functions with angular momenta 2 and 1 and projection quantum numbers m' and m respectively. The product $\chi_{\mathbf{k}_f}^{(-)*} \chi_{\mathbf{k}_i}^{(+)}$ is approximated in the same way as done by Squires. The integrals $I_{m'm}$ can easily be factorized in Cartesian coordinates, which simplifies the calculations considerably.

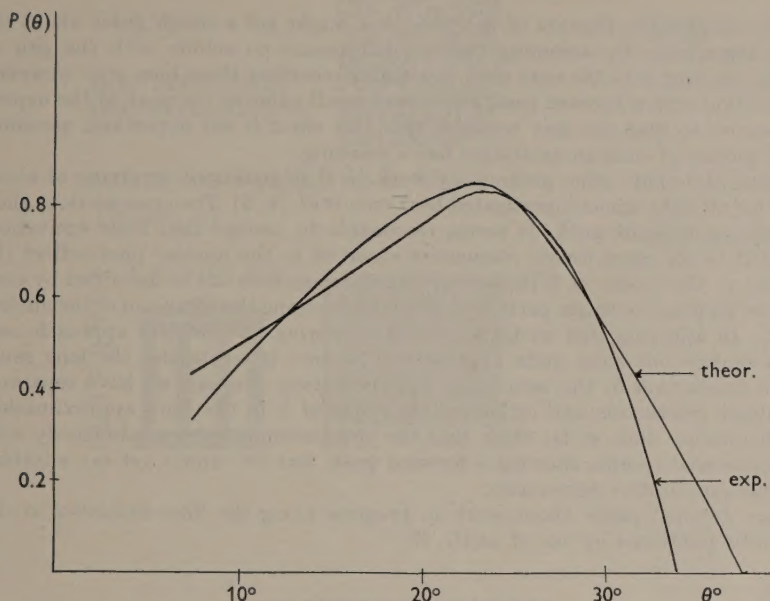


Fig. 2. The experimental and theoretical polarizations.

The polarisation is given by

$$P(\theta) = \frac{2 \operatorname{Re} a^* c}{(|a|^2 + |c|^2)} \quad (4)$$

Figs. 1 and 2 give the results of our calculations together with the experimental results of Tyrén and Maris [6] and Hillman, Johansson and Tyrén [7]. The polarisation agrees very well with the experimental results. Concerning the differential cross-section the agreement is not so good, although somewhat better than that found by Squires for C^{12} . We have also given the curve without absorption, which shows that an exact fit cannot be obtained for any choice of the strength of the imaginary potential (assuming a Gaussian form). The discrepancy between the calculated and experimental cross-sections is probably due to the neglect of collective phenomena in the description of the final state, as discussed by Squires. For O^{16} one might not a priori exclude the possibility of a contribution from an excitation of the nearly lying 0^+ level at 6.05 MeV.¹ If this level is described as an excitation of a pair from the p -shell to the d -shell, this excitation would not be possible in the direct interaction picture, if one uses independent-particle wave functions. If, to take a different point of view, one assumes a strong short-range spatial correlation between the nucleons in the pair, so that the pair can form a narrow wave packet

¹ Note added in proof.—In a subsequent work a different model for the 0^+ -level has been considered, which gives good agreement with experiment (L. Egardt, Nucl. Physics (in press)).

during a considerable fraction of the time, one might get a rough guide about the angular dependence by assuming the incident proton to collide with the pair as an entity, exciting it to the next shell. Estimates according to these lines give, however, a cross-section with a forward peak and a very small value at the peak of the experimental curve, so that one may conclude that this effect is not important, assuming that our picture of such an excitation has a meaning.

We have also made some preliminary work on the excitations occurring at about 20 MeV for all light nuclei investigated by Tyrén *et al.* [8, 6]. The cross-sections show in all cases a forward peak. It seems reasonable to assume that these excitations are related to the giant dipole resonances observed in the nuclear photo-effect [9]. According to the model of Wilkinson [10] these resonances can be described by summing over all possible single particle excitations changing the total spin of the nucleus by unity. In applying this model to proton scattering the *t*-matrix approach used by Squires does not seem quite appropriate, because it treats also the long range Coulomb interaction in the zero range approximation. Instead we have separated the Coulomb interaction and estimated the effect of it in the Born approximation. The calculations done so far show that the cross-sections agree qualitatively with the experimental results, showing a forward peak, but we cannot yet say anything about the quantitative agreement.

A more detailed paper about work in progress along the lines indicated in this note will be published by one of us (L. E).

ACKNOWLEDGEMENTS

We wish to thank Professor I. Waller for his interest and encouragement in this work. We are also indebted to Dr. G. E. Brown, Fil.lic. T. Eriksson and Dr. Th. A. J. Maris for several interesting discussions and suggestions about these problems.

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Tryckt den 6 april 1959

Uppsala 1959. Almqvist & Wiksells Boktryckeri AB